

# LYTIC PEPTIDE PRODRUGS

[0001] This application is a continuation-in-part of application serial number 09/851,422 filed May 9, 2001.

## FIELD OF INVENTION

[0002] This invention relates to methods and compositions for selectively destroying a target cell. Specifically, the invention relates to methods for making and using a procytotoxin that can be converted to a cytotoxin in a tumor-cell specific manner, such that a tumor cell is destroyed by the activated cytotoxin.

## BACKGROUND OF THE INVENTION

[0003] Present methods for tumor treatment, especially cancer treatment, remain sub-optimal and often are accompanied by severe complications. In fact, virtually all of the known therapies have serious adverse side effects, most often caused by the lack of specificity and thoroughness in the destruction or removal of tumor or cancer cells.

[0004] For example, surgery, a common procedure for removing cancerous cells from a patient, often results in incomplete removal and disfigures the patient or interferes with normal bodily functions. Similarly, chemotherapy and radiation treatment often indiscriminately destroys normal cells, causing unwanted side-effects, while leaving many cancer cells unaffected. Chemotherapeutic agents, especially antimetabolites, while effective to varying degrees against cancer cells that are continuously undergoing or preparing for mitosis, are not effective against cancer cells that are in the resting (Go) stage.

[0005] Cancer treatment is most effective when cancer cells can be eliminated as completely as possible from the patient's body. To achieve this goal, continuous or consecutive dosages are administered to the patient. Because most available chemotherapeutic agents are also toxic to normal cells, the dose of cytotoxic drug is adjusted to the limits of tolerance to achieve the maximum destruction of malignant cells, and the interval between doses must be such that the rate of tumor re-growth does not exceed tumor killing. Accordingly, in order to achieve increased efficiency with reduced

side effects, the chemotherapeutic agents should have high target-cell specificity and high target-cell toxicity or potency.

**[0006]** Prostate cancer is the most common form of cancer among males, with an estimated incidence of 30% in men over the age of 50. Overwhelming clinical evidence shows that human prostate cancer has the propensity to metastasize to bone, and the disease appears to progress inevitably from androgen-dependent to androgen-refractory status, leading to increased patient mortality. This prevalent disease is currently the second leading cause of cancer death among men. Prostate cancer metastasis is estimated to claim the lives of over 30,000 Americans each year. In spite of considerable research into therapies for cancer, currently available treatment methods are ineffective in a significant percentage of cases.

**[0007]** Accordingly, there is a need for improved cancer treatment and more methods that are not dependent upon the cell cycle of the cancer cell. Particularly, there is a need for improved treatment methods for prostate cancer. The present invention fulfills these needs and further provides other related advantages.

#### SUMMARY OF THE INVENTION

**[0008]** It therefore is an object of the present invention to overcome some or all of the aforementioned deficiencies in conventional therapies, especially with regard to treating prostate cancer. To this end, compositions and methods for making a procytotoxin are described. A procytotoxin is provided which typically is made up of a cytotoxic peptide bound to an inactivator via a peptide bond, and the peptide bond is susceptible to cleavage by a targeting specific protease. The cytotoxic peptide is preferably a pore-forming cytolytic peptide. The procytotoxin of the present invention may also have a targeting molecule linked to the N- and/or C-terminus of the cytotoxic peptide.

**[0009]** The procytotoxin of the instant invention may also have at least one lysine residue. In general, at least one lysine of the cytotoxin is bound through its  $\epsilon$ -amino group, via an  $\epsilon$ - $\gamma$  peptide bond, to the  $\gamma$ -carboxyl group of a glutamic acid residue. In different embodiments, one, two, or more additional glutamate residues are bound to the one attached to the lysine.

[0010] Generally preferred cytotoxins include Ae I, cytolsin of sea anemone, aerolysin, amatoxin, amoebapore, amoebapore homolog from *Entamoeba dispar*, brevinin-1E, brevinin-2E, barbatolysin, cytolsin of *Enterococcus faecalis*, delta hemolysin, diphtheria toxin, El Tor cytolsin of *Vibrio cholerae*, equinatoxin, enterotoxin of *Aeromonas hydrophila*, esculentin, granulysin, haemolysin of *Vibrio parahaemolyticus*, intermediolysin of *Streptococcus intermedius*, the lentivirus lytic peptide, leukotoxin of *Actinobacillus actinomycetemcomitans*, magainin, melittin, membrane-associated lymphotoxin, Met-enkephalin, neokyotorphin, neokyotorphin fragment 1, neokyotorphin fragment 2, neokyotorphin fragment 3, neokyotorphin fragment 4, NK-lysin, paradaxin, perforin, perfringolysin O, theta-toxin, of *Clostridium perfringens*, phallolysin, phallotoxin, streptolysin, D,L- $\alpha$ -amino acid cyclic peptides, and analogs and derivatives thereof.

[0011] Particularly preferred procytotoxins have the following structures: (1) Gly-Ile-Gly-Ala-Val-Leu-Lys-Val-Leu-Thr-Thr-Gly-Leu-Pro-Ala-Leu-Ile-Ser-Trp-Ile-Lys-Arg-Lys-Arg-Gln-[Gln-Gly-Ala-Ile-Gly-Gln-Pro]-(X), and (2) Gly-Ile-Gly-Ala-Val-Leu-Lys-Val-Leu-Thr-Thr-Gly-Leu-Pro-Ala-Leu-Ile-Ser-Trp-Ile-Lys-Arg-Lys-Arg-Gln-[Gln-Ser-Ser-Phe(or Tyr)-Tyr-Ser-Gly(or Ser)]-(X), wherein (X) is the inactivator as described herein and the peptide marked in brackets can be oriented in either direction. The inactivator, for example, can be a microbead, amino acid, peptide, phage, or phage filament. Preferably, the procytotoxin further contains a targeting molecule. Still preferred, the targeting molecule is a neovascular targeting sequence of an anti-fibronectin ED-B antibody. Also preferred, the targeting molecule is an RGD targeting sequence.

[0012] Other preferred procytotoxins further are charge neutralized, in addition to steric determinants. For example, Gly-Ile-Gly-Ala-Val-Leu-Lys-Val-Leu-Thr-Thr-Gly-Leu-Pro-Ala-Leu-Ile-Ser-Trp-Ile-Lys(R)-Arg-Lys(R)-Arg-Gln-[Gln-Gly-Ala-Ile-Gly-Gln-Pro]-(X), wherein (X) is the inactivator as described herein, the peptide marked in brackets can be oriented in either direction, and wherein R is independently selected from the group consisting of the [unmodified  $\epsilon$ -amino group of the adjacent lysine residue], [ $\epsilon$ - $\gamma$ ]-Glu, [ $\epsilon$ - $\gamma$ ]-Glu- $[\alpha$ - $\gamma$ ](Glu)<sub>1-3</sub>, [ $\epsilon$ - $\alpha$ ](Phe)<sub>1-3</sub>, [ $\epsilon$ - $\alpha$ ](Tyr)<sub>1-3</sub>, [ $\epsilon$ - $\alpha$ ](Trp)<sub>1-3</sub>, [ $\epsilon$ - $\alpha$ ](Lys)<sub>1-3</sub> and [ $\epsilon$ - $\alpha$ ](Arg)<sub>1-3</sub>, wherein [ $\epsilon$ - $\gamma$ ] represents a peptide bond between the epsilon amino group of lysine and the gamma carboxyl group of the adjacent glutamate, [ $\alpha$ - $\gamma$ ] represents a peptide bond between the alpha amino group of the first glutamate and the gamma carboxyl group of the

second glutamate,  $[\epsilon-\alpha]$  represents a peptide bond between the epsilon amino acid of lysine and the alpha carboxyl group of the indicated amino acid and the subscript indicates that additional numbers of the designated amino acid can be linked to the first via conventional peptide bonds.

**[0013]** Also provided, in achieving this objective of the invention, are pharmaceutical compositions that, in general, contain an inventive procytotoxin and a pharmaceutically suitable excipient.

**[0014]** Further, methodology is provided for destroying a target cell selectively. This approach typically entails contacting the target cell with a procytotoxin, which has a cytotoxic peptide bound via a peptide bond to an inactivator, wherein the peptide bond is susceptible to cleavage by a targeting specific protease. Preferred target cells are cancer cells.

**[0015]** Further to the same object, a method for treating a cancer patient is provided. In general, the method comprises administering to a patient in need, a therapeutically effective amount of a pharmaceutical composition containing procytotoxin according to the invention. Preferred compositions contain procytotoxins based on melittin or a cytolytic peptide derived therefrom.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**Figure 1** shows that human prostate cancer cells (LNCaP) are completely lysed after 15 minutes in 50  $\mu\text{M}$  amoebapore helix 3- $\gamma$ -Glu- $\gamma$ -Glu, while mouse L-cells remain unaffected after 24 hours under the same conditions.

**Figure 2** (a) shows the C-terminal sequences of melittin and melittin-like peptides; figure 2(b) illustrates that the  $\epsilon$ -amino groups of the two lysines are coupled with two glutamate residues to neutralize the positive charges of the terminus.

**Figure 3** demonstrates using an ATP depletion assay that human prostate cancer cells (LNCaP) are completely lysed after 1 hour in 50 or 100  $\mu\text{M}$  amoebapore helix 3- $\gamma$ -Glu- $\gamma$ -Glu, while mouse L-cells remain unaffected.

**Figure 4** shows dose responses of various tumors *in vitro* to an inventive masked melittin analog. The numbers 1, 2, 3 and 4 represent 1, 10, 50 and 100  $\mu\text{M}$  analog, respectively.

**Figure 5** shows that an inventive melittin analog selectively lyses PSMA-expressing and cancer cells, but does not lyse cells that do not express PSMA or a similar molecule.

**Figure 6** indicates that prostate tumors treated with melittin-gamma-glutamate are growth-inhibited compared to the untreated control.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention provides compositions and methods for selectively destroying a target cell, like a cancer cell. The composition comprises a procytotoxin that can be activated in a target cell-specific manner, thereby killing, destroying or eliminating the target cell. Methods for making such procytotoxins are also described.

**[0016]** A procytotoxin according to the present invention is a compound that is not itself cytotoxic but may be converted into a cytotoxin. A cytotoxin is a substance that is harmful, destructive or deadly to a cell. A preferred cytotoxin according to the present invention kills or otherwise eliminates the target cell from a patient with high potency.

**[0017]** The pharmaceutical composition according to the instant invention generally does not affect non-target cells. In a preferred embodiment, target cell-specific activation of the procytotoxin occurs only at or near the target cells. When the pharmaceutical composition is used for treating cancer cells, the procytotoxin remains in an inactive state, thus is nontoxic, until it reaches the cancer site. In the case of cancer treatment, the procytotoxin is activated at the surface of the cancer cells and, thereby, it achieves high specificity in the destruction of target cells versus normal cells. Once the procytotoxin is activated in a target cell-specific manner, the high potency of the cytotoxin ensures that the pharmaceutical composition achieves a thorough destruction of the target cells.

#### Cytotoxic Peptides

**[0018]** According to one embodiment of the invention, a procytotoxin is a cytotoxic peptide that is rendered non-toxic by modification of its molecular structure, as detailed below. Many naturally occurring and synthetic cytotoxic peptides are known in the art. Some are useful as therapeutic agents against pathogenic bacteria and other classes of microorganisms; they may be isolated from insects, frogs and other animals. Specific examples include alamethicins, attacins, bactenecins, cecropins (see Table 1 the amino acid

sequences of cecropins A, B and C), CytA and CytB of *Bacillus thuringiensis*, defensins, enterocin L50 (pediocin L50), lantibiotics, magainins, PGLa, protegrins, sapecin, and sarcotoxin.

**[0019]** In another embodiment of the present invention, the procytotoxin is a cytotoxic peptide that is rendered non-toxic by sterically inhibiting formation of an active conformation which renders the peptide toxic. Specifically, the procytotoxin comprises a cytotoxic peptide bound to an inactivator via a peptide bond, wherein said peptide bond is susceptible to cleavage by a targeting specific protease. The inactivator of the instant invention hinders the cytotoxic peptide from forming an active conformation. For example, when the procytotoxin contacts a target cell, a targeting specific protease cleaves the inactivator, thereby allowing the cytotoxic peptide to aggregate with other cytotoxic peptides in their active conformation and form a pore to disrupt a cell membrane.

**[0020]** A preferred cytotoxic peptide is a cytolytic peptide. Cytolytic peptides, also known as channel-forming peptides, typically disrupt cell membranes, causing cell lysis and death upon contact. Many naturally occurring cytolytic peptides from microorganisms, from insects and from higher animals are generally known. They often are called hemolysins because they lyse red blood cells as well as other eukaryotic cells. These toxins include Ae I and other cytolsins of sea anemone, aerolysin, amatoxins, amoebapores, amoebapore homologs from *Entamoeba dispar*, brevinin-1E, brevinin-2E, barbatolysin, cytolsin of *Enterococcus faecalis*, delta hemolysin, diphtheria toxin, El Tor cytolsin of *Vibrio cholerae*, equinatoxins, enterotoxin of *Aeromonas hydrophila*, esculentin, granulysin, haemolysin of *Vibrio parahaemolyticus*, intermedilysin of *Streptococcus intermedius*, the lentivirus lytic peptide, leukotoxin of *Actinobacillus actinomycetemcomitans*, magainin, melittin, membrane-associated lymphotoxin, Met-enkephalin, neokyotorphin and neokyotorphin fragments (1-4), NK-lysin, paradaxins, perforin (especially its amino terminus), perfringolysin O (PFO or theta-toxin) of *Clostridium perfringens*, phallolysins, phallotoxins and streptolysins. Some hemolysins like melittin are also known to kill bacteria.

**[0021]** Other cytolytic peptides include D,L- $\alpha$ -amino acid cyclic peptides selected for lytic activity against mammalian cells. Fernandez-Lopez *et al.*, *Nature*, 412:452-455

(2001). For instance, attaching a D,L- $\alpha$ -amino acid cyclic peptide to a microbead will confer a non-toxic procytotoxin conformation. Accordingly, the procytotoxin may have the following structure: D,L- $\alpha$ -amino acid peptide-MMP cleavage site-Lys-[ $\epsilon$ - $\gamma$ ]-Glu-microbead, wherein the [ $\epsilon$ - $\gamma$ ] represents a peptide bond between the epsilon amino group of lysine and the gamma carboxyl group of the adjacent glutamate. In this example, a target cell that contains a glutamate carboxypeptidase can cleave gamma glutamate peptide bonds.

Preferably, the cytolytic peptide is a pore-forming cytolytic peptide. Many cytolytic peptides are pore-forming toxins, belonging to a group of cytotoxins that associate with cell membranes, either nonspecifically or to specific receptors, and form transmembrane pores of discrete size. Most toxic pore-forming peptides employ common features for their cell lysis activity. For example, a great number of these toxins lyse cells through a "barrel-stave" mechanism, in which monomers of the toxin bind to and insert into the target membrane and then aggregate like barrel staves surrounding a central, water filled pore. This pore causes rapid and irreversible electrolyte imbalance of the target cell leading to its destruction.

**[0022]** Most pore-forming peptides that act on both mammalian and bacterial cells require an amphipathic alpha-helical structure and a net positive charge for their cytolytic activity. A strong electrostatic interaction between the cationic portion of the peptide and the lipid headgroups weakens the membrane, facilitating insertion of the hydrophobic alpha-helical peptides. Accordingly, a particularly preferred cytotoxic peptide according to the invention is a cytolytic, linear  $\alpha$ -helical peptide. Generally these cytotoxic peptides, in their native form, will have a net positive charge, which contributes to their cytolytic activity.

**[0023]** According to a preferred embodiment of the invention, the cytolytic peptide is melittin or an analog or derivative thereof. Melittin is isolated from bee venom and is a 26 amino acid amphiphilic alpha-helix (Blondelle et al., (1991) *Biochemistry* 30: 4671-4678; Dempsey et al., (1991) *FEBS Lett.* 281: 240-244.) The amino acid sequence of melittin is shown in Table 1. Residues 1-20 are predominantly hydrophobic and residues 21 to 26 are hydrophilic and basic. Melittin has antibiotic activity, but in mammals it is lytic for leukocytes, red blood cells and a wide variety of other cells. Compounds similar to melittin, which are also within the scope of the invention, include bombolitin from

bumblebee venom (17 amino acid amphiphilic alpha-helix), mastoparan from wasp venom (14 amino acid amphiphilic alpha-helix) and crabrolin from hornet venom (13 amino acid amphiphilic alpha-helix) Argiolas A. and Pisano J. J., 1985, J. Biol. Chem. 260, 1437-1444.).

**TABLE 1 Amino Acid Sequence of Selected Cytolytic Peptides**

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**Amoebapore Helix 3 (*Entamoeba histolytica*)**

NH<sub>2</sub>-Gly-Phe-Ile-Ala-Thr-Leu-Cys-Thr-Lys-Val-Leu-Asp-Phe-Gly-Ile-Asp-Lys-Leu-Ile-Gln-Leu-Ile-Glu-Asp-Lys-COOH

**Cecropin A (*Antheria pernyi*)**

NH<sub>2</sub>-Lys-Trp-Lys-Leu-Phe-Lys-Lys-Ile-Glu-Lys-Val-Gly-Gln-Asn-Ile-Arg-Asp-Gly-Ile-Ile-Lys-Ala-Gly- Pro-Ala-Val-Ala-Val-Val-Gly-Gln-Ala-Thr-Gln-Ile-Ala-Lys-COOH

**Cecropin B (*Antheria pernyi*)**

NH<sub>2</sub>-Lys-Trp-Lys-Ile-Phe-Lys-Lys-Ile-Glu-Lys-Val-Gly-Arg-Asn-Ile-Arg-Asn-Gly-Ile-Ile-Lys-Ala-Gly-Pro-Ala-Val-Ala-Val-Leu-Gly-Glu-Ala-Lys-Ala-Leu-COOH

**Cecropin D (*Antheria pernyi*)**

NH<sub>2</sub>-Trp-Asn-Pro-Phe-Lys-Glu-Leu-Glu-Lys-Val-Gly-Gln-Arg-Val-Arg-Asp-Ala-Val-Ile-Ser-Ala-Gly-Pro-Ala-Val-Ala-Thr-Val-Ala-Gln-Ala-Thr-Ala-Leu-Ala-Lys-COOH

**Melittin (*Apis mellifera*)**

NH<sub>2</sub>-Gly-Ile-Gly-Ala-Val-Leu-Lys-Val-Leu-Thr-Thr-Gly-Leu-Pro-Ala-Leu-Ile-Ser-Trp-Ile-Lys-Arg-Lys-Arg-Gln-Gln-COOH

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**[0024]** A particularly preferred pore-forming peptide, according to the instant invention, is amoebapore, a 77-residue pore-forming peptide from the amoebae *Entamoeba histolytica* (Young *et al.*, (1982) J. Exp. Med. 156: 1677; Lynch *et al.*, (1982) EMBO J 7:



801; Young & Cohn, (1985) J. Cell Biol. 29: 299; Rosenberg *et al.*, (1989) Molec. Biochem. Parasit. 33: 237; Jansson *et al.*, (1994) Science 263: 1440). It has four alpha helices, from amino acids approximately 1-21, 25-36, 40-63 and 67-77, conventionally called helices 1, 2, 3, and 4, respectively.

**[0025]** Three isoforms of amoebapore are known: amoebapore A, B and C, respectively. This peptide is stabilized by three disulfide bonds and contains four mostly amphipathic alpha-helical structures. The third amphipathic helical structure (helix 3) retains the cytolytic activity similar to the wild type peptide. A synthetic peptide based on the sequence of its third amphipathic alpha helix have recently been shown to have cytolytic activity for nucleated cells at high concentrations (10-100  $\mu$ M) (Leippe *et al.*, (1994) Proc. Natl. Acad. Sci. USA 91: 2602). Accordingly, a particularly preferred cytotoxin is an amoebapore derivative listed in Table I: NH<sub>2</sub>-Gly-Phe-Ile-Ala-Thr-Leu-Cys-Thr-Lys-Val-Leu-Asp-Phe-Gly-Ile-Asp-Lys-Leu-Ile-Gln-Leu-Ile-Glu-Asp-Lys-COOH.

**[0026]** It is readily recognized that the above described cytolytic peptides may be modified or derivatized to produce analogs and derivatives which retain, or even exhibit enhanced, cytolytic activities. For example, Andra *et al.* disclose that shortened amoebapore analogs have enhanced antibacterial and cytolytic activities (FEBS Letters, 385 (1996), pp. 96-100, incorporated herein by reference in its entirety).

**[0027]** In designing such analogs or derivatives, the artisan will be informed by the foregoing discussion relating to the amphipathic alpha-helical structure and net positive charge that are implicated in the cytolytic activity. Thus, a skilled artisan is able to design amoebapore analogs, *i.e.*, non-native forms never before known in nature, based on the observed homologies and known structure and properties of the native protein, to be used as a cytolytic peptide in accordance with the instant invention.

**[0028]** Modification and derivatization according to the instant invention include, but are not limited to, substitutions, additions or deletions that provide for functionally equivalent molecules. (Function may be assessed in accord with the working examples presented below.) Analogs and derivatives may also be made via modifications of side chains of amino acid residues of the cytotoxic peptides, preferably, with enhanced or increased functional activity relative to the native protein or polypeptide.

**[0029]** For example, analogs and derivatives of an amoebapore or other cytolytic peptides include, but are not limited to, those containing, as a primary amino acid sequence, all or part of the amino acid sequence the native peptide, such as with altered sequences in which functionally equivalent amino acid residues are substituted for residues within the sequence resulting in a conservative amino acid substitution. For example, one or more amino acid residues within the sequence can be substituted by another amino acid of a similar polarity, which acts as a functional equivalent, resulting in a silent alteration. Substitutes for an amino acid within the sequence may be selected from other members of the class to which the amino acid belongs. For example, nonpolar (hydrophobic) amino acids include alanine, leucine, isoleucine, valine, proline, phenylalanine, tryptophan and methionine. Polar neutral amino acids include glycine, serine, threonine, cysteine, tyrosine, asparagine, and glutamine. Positively charged (basic) amino acids include arginine, lysine and histidine. Negatively charged (acidic) amino acids include aspartic acid and glutamic acid. Because the terminal positive charges are thought to be involved in the cytolytic activity of the peptide, addition or substitution of a positively charged amino acid at the C-terminus is particularly contemplated to enhance its cytolytic potency.

**[0030]** Dimerization, truncation, diastereoisomers (D-amino acid-incorporated analogs) (Shai *et al.*, (1996) J. Biol. Chem. 271-7305-7308), and combinations thereof may also be employed for producing derivatives and analogs of pore-forming peptides. For example, Werkmeister *et al.* (1993), Biochim. Biophys. Acta 1157: 50-54, discloses the effect of sequence and structural variations on the cytolytic activity of melittin, and is hereby incorporated by reference in its entirety.

**[0031]** The cytolytic peptides of the invention will normally contain from about 15 to about 40 amino acid residues. It is apparent to one skilled in the art that active low molecular weight peptides containing less than about 40 amino acids (or even less than about 30) are normally not difficult to synthesize chemically, while peptides with more than about 40 amino acids are relatively difficult to synthesize in pure form by chemical methods, and may be best prepared by fermentation or by recombinant DNA procedures from the appropriate genetic coding sequence.

[0032] A particular advantage of the useful peptides of this invention is that they are readily synthesized by solid phase methods and a variety of combinations are possible to achieve specifically required results. An advantage of the use of solid phase techniques is that the product can be directly synthesized with the C-terminus amidated or otherwise blocked, which is beneficial in forming the procytotoxins of the invention. For example, one procytotoxin requires formation of  $\gamma$ -glutamate peptide bonds which are readily produced by such chemical synthesis.

#### Inactivator

[0033] An inactivator according to the present invention is an object that, when attached to a lytic peptide, inactivates the cytotoxin by charge neutralization and/or sterically inhibiting formation of a conformation which renders the peptide toxic. The inactivator, for example, may be a phage via phage engineering or a streptavidin microbead via peptide biotinylation. Therefore, the procytotoxin may comprise the following structure: lytic peptide-MMP2 cleavage site-Lys-[ $\epsilon$ - $\gamma$ ]-biotin-streptavidin coated microbead. Accordingly, cells with a matrix metalloprotease (specifically, MMP-2) will cleave the procytotoxin at the MMP-2 cleavage site. The lytic peptide can now fold into its active conformation and aggregate with other cytolytic peptides to form a pore and lyse the target cell. The inactivator may also be a negatively charged amino acid, such as glutamic acid or aspartic acid.

[0034] The inactivator may also be an amino acid, but is typically a peptide. The peptide may vary in size and in fact, need not be "big". So long as the amino acids charge neutralize and/or create steric restriction of lytic peptide membrane insertion and organization into a pore, the peptide is a suitable inactivator.

[0035] The inactivator can be added to the N- or C-terminus of the cytotoxic peptide, or both. In a preferred embodiment, the cytotoxic peptide is a cytolytic peptide, and the inactivator is added to the C-terminus of a cytolytic peptide. Furthermore, the inactivator may additionally comprise a targeting molecule, as discussed below.

#### Targeting specific protease

[0036] A targeting specific protease as described herein is an enzyme associated with a target cell that cleaves a peptide bond of proteins. A target cell, as described herein,

may be any cell whose lysis is desired. For example, a target cell could be a cancer cell, a bacterial cell, or endothelial cells of the tumor neo-vasculature.

[0037] The targeting specific protease of the present invention may be typically expressed in tumors, but need not be exclusively expressed in tumors. Accordingly, the targeting specific protease may be preferentially expressed in tumor cells when compared to normal cells. Additionally, the targeting specific protease may be a protease expressed by a non-tumorigenic target cell, such as a bacterial cell, but is nevertheless preferentially expressed by a target cell when compared to a non-target cell. Accordingly, the procytotoxin as described herein is additionally useful as an antimicrobial or antibacterial agent.

[0038] In a preferred embodiment, the targeting specific protease is MMP. Still preferred, the targeting specific protease is MMP-2. MMPs are associated with angiogenesis, as well as neo-vessel formation. Therefore, targeting the vasculature which supplies the tumors, as well as newly formed vessels, prevents tumors from forming.

[0039] For example, lytic peptides of the instant invention linked to an inactivator by a sequence of amino acids recognized by MMP can be selectively released from the inactivator in the presence of a targeting specific protease such as MMP. The cytotoxic peptide is then free to form its active conformation and lyse target cells.

[0040] Additional reactive peptide substrates suitable for the present invention include those described for PSA in Coombs *et al.*, *Chem Biol*, 5(9):475-88 (1988), PSMA and gamma-glutamyl hydrolase (GGH).

#### Targeting Molecule

[0041] The targeting molecule of the instant invention is an optional feature that presents an extra measure of selectivity. The targeting molecule directs the procytotoxin to the target cell, where the procytotoxin is rendered toxic and selectively lysis its target. Additionally, the targeting molecule may act as an inactivator of the cytolytic peptide. In this regard, the targeting molecule may charge neutralize or sterically inhibit a cytolytic peptide from pore formation. The targeting molecule may be added to the N- or C-terminus, or both.

**[0042]** In a preferred embodiment, the targeting molecule is an antibody. Preferably, the antibody is an anti-fibronectin ED-B antibody, thereby directing the procytotoxin to the extracellular matrix associated with neo-vessel formation. The antibody in the instant invention can be a full-length (i.e., naturally occurring or formed by normal immunoglobulin gene fragment recombinatorial processes) immunoglobulin molecule (*e.g.*, an IgG antibody) or an immunologically active (i.e., specifically binding) portion of an immunoglobulin molecule.

**[0043]** Antibody fragments which recognize specific epitopes can be generated by known techniques. For example, such fragments include, but are not limited to: the F(ab)<sub>2</sub> fragments which can be produced by pepsin digestion of the antibody molecule and the Fab' fragments, which can be generated by reducing disulfide bridges of the F(ab)<sub>2</sub> fragments. Alternatively, Fab' expression libraries can be constructed (Huse *et al.*, 1989, *Science*, 246:1274-1281) to allow rapid and easy identification of monoclonal Fab' fragments with the desired specificity.

**[0044]** The antibodies described herein can be polyclonal or monoclonal antibodies. Polyclonal antibodies are heterogeneous populations of antibody molecules derived from the sera of animals immunized with antigen, such as a target gene product, or an antigenic functional derivative thereof. Monoclonal antibodies are homogeneous populations of antibodies to a particular antigen and the antibody comprises only one type of antigen binding site to which the nucleic acid specifically binds.

**[0045]** Targeting molecules that target the neo-vasculature can also be added to the inactivator. Molecules that target the neo-vasculature can easily be identified by screening phage display libraries. Any such peptide would be a suitable targeting molecule of the present invention.

**[0046]** Targeting molecules which bind specifically to integrins are one class of molecules that target the neovasculature. These peptides bear the sequence based on Arg-Gly-Asp (RGD). Accordingly, sequences that bind certain integrins can serve as a useful targeting molecules to endothelial cells and other cells of the neo-vasculature. In a preferred embodiment, the targeting molecule is an RGD targeting sequence.

**[0047]** Non-structural spacers may be a feature of the targeting molecule. Such spacers typically comprise glycine and/or proline residues. Preferably lengths of these spacers range from about one to about 5 amino acids, with two being particularly preferred. In addition, it is often preferable to physically constrain the targeting molecule by cyclization, which usually results in increased binding. This is usually accomplished by a pair of cysteine residues, flanking the RGD core at a distance of about 4 (having only RGD in between) to 10 amino acids from one another, and preferably about 7 amino acids from one another.

**[0048]** Thus, a typical targeting molecule would have the following structure:

-XRGDYX-

wherein X is zero to five amino acids and Y is a one or two amino acids, selected from cysteine, serine, threonine and methionine. In a particularly useful embodiment, X is comprised of glycine residues, but optionally contains at least one, and typically one or two, free thiol- or amine-containing amino acids and/or a single hydrophobic amino acid. Thiol-containing residues include methionine and cysteine; amine-containing residues include lysine and (at least one additional) arginine; and hydrophobic residues include leucine, isoleucine, alanine and phenylalanine.

**[0049]** Unless otherwise indicated by context, the term “RGD” refers not only to the peptide sequence Arg-Gly-Asp, it refers generically to the class of minimal or core peptide sequences that mediate specific interaction with integrins. Thus, an “RDG targeting sequence” encompasses the entire genus of integrin-binding domains.

#### Procytotoxins

**[0050]** In order to enhance its therapeutic usefulness, a cytotoxin is modified according to the invention to its non-toxic form, known as a procytotoxin. Accordingly, a method for making a procytotoxin, comprising modifying a cytotoxic peptide to include an inactivator, is described.

**[0051]** Numerous methods of modifications are available, the applicability of which will depend on the structural characteristics of the cytotoxin. A peptide, for example, may be added to either the N-terminus and/or C-terminus of the cytotoxic peptide, such that the cytotoxic peptide is sterically hindered and therefore rendered non-

toxic. Sterically preventing the alpha-helical structure of the cytotoxin from forming or inhibiting the organization of multiple proteins required for pore formation, is a preferred embodiment. Additionally, the cytotoxic peptide can be modified to include negatively charged amino acids, thereby preventing aggregation of multiple proteins into a toxic pore conformation.

**[0052]** The procytotoxin of the present invention comprises a cytotoxic peptide bound to an inactivator via a peptide bond, wherein said peptide bond is susceptible to cleavage by a targeting specific protease. Preferably, the cytotoxic peptide is a pore-forming cytolytic peptide, as described above. Still preferred, the cytolytic peptide is a melittin, a melittin analog, or a melittin derivative.

**[0053]** For instance, the procytotoxin of the present invention comprises the following structure: Gly-Ile-Gly-Ala-Val-Leu-Lys-Val-Leu-Thr-Thr-Gly-Leu-Pro-Ala-Leu-Ile-Ser-Trp-Ile-Lys-Arg-Lys-Arg-Gln-[Gln-Gly-Ala-Ile-Gly-Gln-Pro](X), wherein (X) is an inactivator and the peptide marked in brackets can be oriented in either direction. The inactivator can be selected from the group consisting of a microbead, an amino acid, a peptide, phage and a phage filament. Cleavage by MMP at this peptide will yield a melittin peptide with few additional amino acids on the C-terminus (Gly-Ala-Ile) which should not interfere with pore formation.

**[0054]** In a related vein, the procytotoxin of the present invention comprises Gly-Ile-Gly-Ala-Val-Leu-Lys-Val-Leu-Thr-Thr-Gly-Leu-Pro-Ala-Leu-Ile-Ser-Trp-Ile-Lys-Arg-Lys-Arg-Gln-[Gln-Ser-Ser-Phe(or Tyr)-Tyr-Ser-Gly(or Ser)](X), wherein (X) is an inactivator and the peptide marked in brackets can be oriented in either direction. Cleavage of this peptide with PSA will render the peptide toxic.

**[0055]** Also contemplated in the instant invention is a targeting molecule that adds an additional measure of selectivity. For example, the procytotoxin may comprise the following structure: lytic peptide-[Gln-Gly-Ala-Ile-Gly-Gln-Pro]-Lys-[ $\epsilon$ - $\gamma$ ]-biotin-streptavidin coated microbead-RGD targeting sequence.

**[0056]** In addition to directing the procytotoxin in or around the cell, the targeting molecule may act as an inactivator as well, maintaining the cytolytic peptide in its inactive

state. A targeting molecule of the instant invention may be selected from the group consisting of a molecule that targets the neovasculature and an antibody. In a preferred embodiment, the targeting molecule is an RGD targeting sequence.

**[0057]** Furthermore, the procytotoxin may also comprise at least one lysine residue bound via a peptide bond to at least one amino acid via the  $\epsilon$ -amino group of said lysine residue. The inventors have recognized that a common feature of some of the aforementioned cytotoxins is the presence of one or more lysine residues. Accordingly, a preferred means of preparing a protoxin is to modify one or more of these lysine residues. Thus, for example, by addition via a peptide bond of a negatively charged inactivator, such as an amino acid, to the epsilon amino group of lysine, charge neutralization and/or steric mechanisms are invoked to maintain the toxin as a protoxin. Of course, where a native molecule lacks a lysine, it may be added and modified, which still is expected to invoke the steric inhibition of toxin formation. Generally, the amino acid added to the epsilon amino group using a peptide linkage will be the target of a membrane-associated protease. An increasing number of such enzymes are being identified which are correlated with neoplastic or preneoplastic states. Thus, they are convenient targets for therapy.

**[0058]** In one aspect protoxin formation is accomplished via the conversion of an epsilon amino group of a lysine residue to a neutral peptide linkage and/or the addition of one or more negatively charged amino acid residues at or near this position. A preferred negatively charged amino acid is glutamate. In a particularly preferred embodiment the epsilon amino group of lysine is bound by a peptide linkage to the gamma carboxyl group of glutamate. The resultant free alpha carboxyl group in such a case is free to neutralize additional adjacent positively charged amino acids, like arginine, which is expected to further repress the activity of the cytotoxin. In some embodiments it is envisioned that more than one glutamic acid (poly- $\alpha$ - $\gamma$ -glutamate) is added to a lysine. Thus, a peptide lysine is bound via an  $\epsilon$ - $\gamma$  linkage to a glutamate and that glutamate is bound to a second glutamate via an  $\alpha$ - $\gamma$  peptide bond. The second glutamate may be bound to a third, and so on.

**[0059]** It will be apparent to the artisan, therefore, that a more general aspect of the invention entails adding any amino acid to partially or wholly neutralize the subject



positive charge, or otherwise to sterically inhibit formation of the toxin. For example, where a lysine residue is present, as described above, any amino acid may be linked to the epsilon amino group, via a linkage with the alpha carboxyl group of the added amino acid. In general, a salient feature is the ability of the added amino acid to be proteolytically cleaved in order to form toxin from protoxin. Thus, in the case of chymotrypsin-like activity, the bulky hydrophobic amino acids, like tyrosine, phenylalanine and tryptophan may be employed. In a case where steric considerations alone are sufficient to inactivate the toxin, positively charged amino acids like arginine and lysine may be employed to invoke trypsin-like activity. Other examples also are apparent based on the artisan's knowledge of protease specificity's.

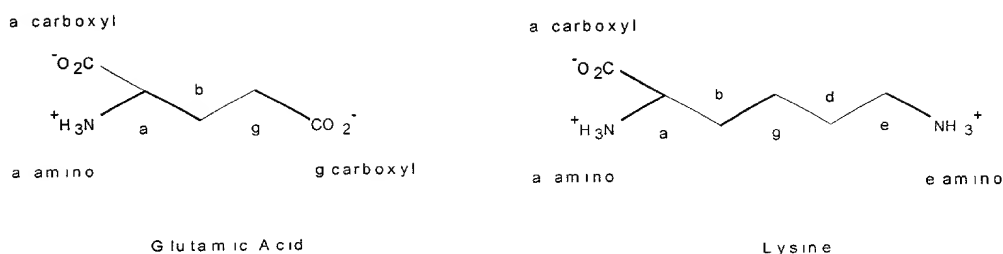
**[0060]** Particularly preferred procytotoxins include amoebapore, its analogs and its derivatives that contains one or more  $\gamma$ -linked glutamate residues linked via a peptide bond to the epsilon amino group of at least one lysine, preferably the C-terminal-most lysine (hereinafter " $\gamma$ -glutamate-masked amoebapore analog"). A particularly preferred procytotoxin has the following structure: Gly-Phe-Ile-Ala-Thr-Leu-Cys-Thr-Lys-Val-Leu-Asp-Phe-Gly-Ile-Asp-Lys-Leu-Ile-Gln-Leu-Ile-Glu-Asp-Lys- $[\epsilon-\gamma]$ -Glu- $[\alpha-\gamma]$ -Glu, wherein  $[\epsilon-\gamma]$  represents a peptide bond between the epsilon amino group of lysine and the gamma carboxyl group of the adjacent glutamate and  $[\alpha-\gamma]$  represents a peptide bond between the alpha amino group of the first glutamate and the gamma carboxyl group of the second glutamate.

**[0061]** In addition, amoebapore and other cytotoxic peptides can be modified with other amino acids. One such exemplary protoxin has the following structure: Gly-Phe-Ile-Ala-Thr-Leu-Cys-Thr-Lys-Val-Leu-Asp-Phe-Gly-Ile-Asp-Lys-Leu-Ile-Gln-Leu-Ile-Glu-Asp-Lys- $[\epsilon-\alpha]$ -Phe, wherein  $[\epsilon-\alpha]$  represents a peptide bond between the epsilon amino group of lysine and the alpha carboxyl group of the adjacent phenylalanine. Another exemplary protoxin that can be activated by chymotrypsin-like activity has the following structure: Gly-Phe-Ile-Ala-Thr-Leu-Cys-Thr-Lys-Val-Leu-Asp-Phe-Gly-Ile-Asp-Lys( $[\epsilon-\alpha]$ -Phe)-Leu-Ile-Gln-Leu-Ile-Glu-Asp-Lys- $[\epsilon-\alpha]$ -Phe, using the same nomenclature and where Lys( $[\epsilon-\alpha]$ -Phe)-Leu represents a linkage between the epsilon amino group of lysine and the alpha carboxy group of phenylalanine, and a standard peptide linkage between lysine and phenylalanine. Of course, the phenylalanine may be replaced with other amino acids, such

as tyrosine and tryptophan in the case of chymotrypsin-like activity. In some instances, in order to invoke trypsin-like activity, it may be beneficial to utilize positively charged amino acids, like arginine and lysine, instead of phenylalanine.

**[0062]** Other particularly preferred procytotoxins include melittin, its analogs and its derivatives that contain at least one  $\gamma$ -linked glutamate residue linked via a peptide bond to the epsilon amino group of a lysine (hereinafter " $\gamma$ -glutamate-masked melittin analog"). As indicated in Table 1, melittin has two lysines and two adjacent arginines near its C-terminus. When one of the lysines is so masked, it is expected that the free alpha carboxyl group would act to neutralize the adjacent arginine, further contributing to the inhibition of the toxic activity of melittin. A particularly preferred procytotoxin has the following structure: Gly-Ile-Gly-Ala-Val-Leu-Lys-Val-Leu-Thr-Thr-Gly-Leu-Pro-Ala-Leu-Ile-Ser-Trp-Ile-Lys( $[\epsilon-\gamma]$ -Glu)-Arg-Lys( $[\epsilon-\gamma]$ -Glu)-Arg-Gln-Gln, wherein -Lys( $[\epsilon-\gamma]$ -Glu)-Arg- represents a peptide bond between the epsilon amino group of lysine and the gamma carboxyl group of the adjacent glutamate and a standard peptide bond between the lysine and arginine residues. Of course, -Lys( $[\epsilon-\gamma]$ -Glu)-Arg- can be replaced, for example, by -Lys( $[\epsilon-\alpha]$ -Phe)-Leu-, as detailed above, and phenylalanine can be replaced by other amino acids like tyrosine and tryptophan to invoke chymotrypsin-like activity. In some instances, when trypsin-like activity is being invoked, it may be beneficial to utilize positively charged amino acids, like arginine and lysine, instead of phenylalanine in this latter example.

**[0063]** With regard to the terminology used herein, the artisan will recognize that a "standard" peptide bond is formed between the alpha carboxyl group of one amino acid with the alpha amino group of the next amino acid in the peptide chain and that peptide sequences are read from their amino-terminal end to their carboxyl-terminal end. For clarification, the following structures of glutamic acid and lysine are presented with the various groups named according to which carbon of the amino acid backbone they attach:



**[0064]** A set of particularly preferred procytotoxins have the following structures: (1) Gly-Phe-Ile-Ala-Thr-Leu-Cys-Thr-Lys(R)-Val-Leu-Asp-Phe-Gly-Ile-Asp-Lys(R)-Leu-Ile-Gln-Leu-Ile-Glu-Asp-Lys(R), and (2) Gly-Ile-Gly-Ala-Val-Leu-Lys(R)-Val-Leu-Thr-Thr-Gly-Leu-Pro-Ala-Leu-Ile-Ser-Trp-Ile-Lys(R)-Arg-Lys(R)-Arg-Gln-Gln, wherein R is independently selected from the group consisting of the  $\epsilon$ -amino group of the adjacent lysine residue,  $[\epsilon-\gamma]$ -Glu,  $[\epsilon-\gamma]$ -Glu- $[\alpha-\gamma]$ -(Glu)<sub>1-3</sub>,  $[\epsilon-\alpha]$ -(Phe)<sub>1-3</sub>,  $[\epsilon-\alpha]$ -(Tyr)<sub>1-3</sub>,  $[\epsilon-\alpha]$ -(Trp)<sub>1-3</sub>,  $[\epsilon-\alpha]$ -(Lys)<sub>1-3</sub> and  $[\epsilon-\alpha]$ -(Arg)<sub>1-3</sub>, wherein  $[\epsilon-\gamma]$  represents a peptide bond between the epsilon amino group of lysine and the gamma carboxyl group of the adjacent glutamate,  $[\alpha-\gamma]$  represents a peptide bond between the alpha amino group of the first glutamate and the gamma carboxyl group of the second glutamate,  $[\epsilon-\alpha]$  represents a peptide bond between the epsilon amino acid of lysine and the alpha carboxyl group of the indicated amino acid and the subscript indicates that additional numbers of the designated amino acid can be linked to the first via conventional peptide bonds. With regard to the subscripted numbers, it is understood that larger numbers of amino acids are possible, *e.g.*, 4, 5, 6, *etc.*, but 1, 2, and 3 are anticipated to be optimal.

**[0065]** It is therefore also understood that in addition to or instead of steric determinants, charge determinants are also important. Where the positive charge of the pore forming peptide is involved in its cytolytic activity, eliminating/neutralizing the charge renders the peptide non-toxic. It is envisioned that even a partial neutralization of this positive charge will be effective. Accordingly, disrupting the alpha helical structure of the cytotoxin by sterically preventing the structure from forming in addition to eliminating/neutralizing the positive charge of the pore-forming peptide is also preferred. Thus, even if no neutralization is accomplished, some of the modifications below will result in steric alterations which will inactivate the toxin to create the protoxin.

[0066] While not wishing to be bound by any theory, the inventors recognize the importance of the positive charges for the mode of action of the amoebapore and related cytotoxic molecules, and believe that the glutamate residues added according to the invention neutralize and reverse the polarity of these positive charges of a cytolytic peptide or its analog or derivative, thus negating its cell-lysing activities. In the case of other amino acids, they may function by a partial neutralization. Of course, steric determinants also are believed to be important in maintaining the toxins in protoxin form in many, if not all cases.

[0067] The procytotoxic peptides of this invention may be chemically synthesized by standard solid phase procedures using the protection, deprotection and cleavage techniques and reagents appropriate to each specific amino acid or peptide. A combination of manual and automated (e.g., APPLIED BIOSYSTEM.®™ 430A) solid phase techniques can be used to synthesize the novel peptides of this invention. For background on solid phase techniques, reference is made to Andreu *et al.*, (1983) Proc. Natl. Acad. Sci USA 80: 6475-6479; Andreu *et al.*, (1985) Biochemistry 24: 1683-1688; Fink *et al.* (June 1989) Int. J. Peptide Protein Res. 33: 412-421; Fink *et al.*, (1989) J. Biol. Chem. 264: 6260-6267; each of which is incorporated herein by reference.

[0068] The *in vivo* stability of the procytotoxin of the invention can be improved by adding a D-amino acid to the N- or C-terminus, whichever does not have a  $\gamma$ -linked glutamic acid residue. (Of course, some *in vivo* instability would be advantageous because it would decrease the chance of possible adverse side effects that might arise once the procytotoxin is converted to cytotoxin.) This procedure is particularly useful with products of the invention which are employed under conditions, parenteral or oral, where they will be subject to hydrolysis by naturally occurring enzymes before they perform their desired physiological function.

#### Pharmaceutical Compositions

[0069] Another aspect of the present invention is a pharmaceutical composition comprising one or more procytotoxins of the invention and a pharmaceutically suitable carrier or excipient.

[0070] While a procytotoxic peptide of the present invention can be administered, alone, to a patient, it is preferable to present the peptide as part of a pharmaceutical formulation. It is also preferred to administer more than one procytotoxin, or combinations of procytotoxins as part of a pharmaceutical formulation. Pharmaceutically suitable excipients typically include carriers known to those skilled in the art, including pharmaceutical adjuvants. Generally, these pharmaceutically acceptable carriers will include water, saline, buffers, and other compounds described, e.g., in the MERCK INDEX, Merck & Co., Rahway, N.J. See also Bioreversible Carriers in Drug Design, Theory and Application, Roche (ed.), Pergamon Press, (1987). These formulations typically comprise the pharmacological agent (i.e., the procytotoxin) in a therapeutically or pharmaceutically effective dose together with one or more pharmaceutically or therapeutically acceptable carriers and optionally other therapeutic ingredients. Various considerations are described, e.g., in Gilman *et al.* (eds) (1990) Goodman and Gilman's: The Pharmacological Bases of Therapeutics, 8th Ed., Pergamon Press; Novel Drug Delivery Systems, 2nd Ed., Norris (ed.) Marcel Dekker Inc. (1989), and Remington's Pharmaceutical Sciences, the full disclosures of which are incorporated herein by reference.

[0071] The compositions may be formulated in any pharmaceutical form appropriate for the desired route of administration. Examples of such compositions include solid compositions for oral administration such as tablets, capsules, pills, powders and granules which may be enteric coated or otherwise protected from hydrolysis, especially enzymatic hydrolysis, liquid compositions for oral administration such as solutions, suspensions, syrups or elixirs and preparations for parenteral administration such as sterile solutions, suspensions or emulsions. The compositions may also be manufactured in the form of sterile solid compositions which can be dissolved in sterile water, physiological saline or some other sterile injectable medium immediately before use.

[0072] Since the procytotoxins of the invention are amphoteric they may be utilized as free bases, as acid addition salts or as metal salts. The salts must, of course, be pharmaceutically acceptable, and these will include metal salts particularly alkali and alkaline earth metal salts, suitably potassium or sodium salts. A wide variety of pharmaceutically acceptable acid addition salts are available. These include those prepared from both organic and inorganic acids, preferably mineral acids. Typical acids which may

be mentioned by way of example include citric, succinic, lactic, hydrochloric and hydrobromic acids. Such products are readily prepared by procedures well known to one skilled in the art.

[0073] In all such compositions, the cytolytic peptides will normally be the principal physiologically active ingredient. The inventive peptides may be formulated, however, with additional pharmacological agents for combination therapies. When used in treating cancer, for example, they may be formulated with compatible conventional chemotherapeutic agents.

[0074] Methods for administration are also discussed in Gilman *et al.* (eds) (1990) and Norris (ed.), *supra*. In particular, the pharmaceutical composition of the invention may be administered intravenously, subcutaneously, orally, transdermally, such as in the method of (Prausnitz, M R, Bose, V G, Langer, R, Weaver, J C: Electroporation of Mammalian skin: a mechanism to enhance transdermal drug delivery. Proc. Nat'l. Acad. Sci. U.S.A., 90:10504-10508 (1993); and Wallace, B M, Lasker, J S: Stand and Deliver: getting peptide drugs into the body. Science 260:912-912 (1992). Liposomes may also be used to administer the procytotoxin of the invention (see Woodle, M C, Storm, G, Newman, M S, Jekot, J J, Collins, L R, Martin, F J, Szoka F C: Prolonged systemic delivery of peptide drugs by long circulating liposomes: illustration with vasopressin in the Brattleboro rat. Pharmaceut. Res. 9:260-265 (1992).

[0075] Therefore, a method for treating a cancer patient, comprising administering a therapeutically effective amount of the pharmaceutical compositions of the instant invention is described. More than one procytotoxin may be administered, and combinations of procytotoxins may also be administered. Optimal delivery routes, dosages and regimens for a given mammalian host can be readily ascertained by one skilled in the art. It will, of course, be appreciated that the actual dose used will vary according to the particular composition formulated, the particular compound used, the mode of application and the particular site, host and disease being treated. Many factors that modify the action of the drug will be taken into account including age, weight, sex, diet, time of administration, route of administration, rate of excretion, condition of the patient, drug combinations, reaction sensitivities and severity of the disease.

Method of Selectively Destroying a Target Cell

**[0076]** The peptide protoxin of the present invention typically is converted, and thereby activated, into a cytotoxic peptide in a target cell-specific manner by an activity associated with the target cell. In other words, the target cell possesses a specific mechanism for converting the procytotoxin into a cytotoxin. The activated cytotoxic peptide assembles with other cytotoxic peptides and destroy a target cell in a selective manner. Most conveniently, this cell-associated activity is a protease.

**[0077]** Accordingly, a method for selectively destroying a target cell, comprising contacting the target cell with procytotoxin, which comprises a cytotoxic peptide bound via a peptide bond to an inactivator, wherein said peptide bond is susceptible to cleavage by a targeting specific protease, is described. Preferably, the target cell is a cancer cell, but any cell that comprises the targeting specific protease may be a target.

**[0078]** Preferably, the target cell has a protease that selectively cleaves the peptide bond to which the inactivator is attached. Therefore, if the procytotoxin comprises an MMP cleavage site, a target cell with an MMP can cleave the peptide bond and “activate” the cytolytic peptide. Also preferred, the procytotoxin comprises a targeting molecule selected from the group consisting of an RGD targeting sequence and a neovascular targeting sequence of an anti-fibronectin ED-B antibody. These targeting sequences may act as inactivators themselves, as well as direct a procytotoxin to the neo-vasculature and cytoskeletal elements surrounding the target cell.

**[0079]** In another preferred embodiment, the procytotoxin of the instant invention further comprises a cytotoxic peptide having at least one lysine residue bound via a peptide bond to at least one amino acid via the  $\epsilon$ -amino group of said lysine residue. Preferably, the epsilon amino group of lysine is bound by a peptide linkage to the gamma carboxyl group of a glutamate. A target cell that contains a glutamate carboxypeptidase can cleave gamma glutamate peptide bonds. Consequently, when a  $\gamma$ -glutamate-masked cytolytic peptide is contacted with a target cell that contains a glutamate carboxypeptidase, the  $\gamma$ -glutamate residues are removed from the protoxin, and the resultant cytolytic peptide molecule causes lysis of the target cell. A non-target cell, which does not contain the

glutamate carboxypeptidase, is unable to activate the protoxin and is thus unaffected by the protoxin.

**[0080]** A skilled person would readily recognize that if the glutamate residue is linked to the  $\epsilon$ -amino group of a lysine, a carboxypeptidase, including the prostate specific membrane antigen discussed below, would be able to cleave the  $\gamma$ -linked glutamate residues regardless whether they are located at the C-terminus or the N-terminus of the cytotoxic peptide or somewhere in between.

**[0081]** Thus, it will be recognized that such an approach has broader applicability to cells associated with a particular activity that can be invoked to convert the protoxin to its toxin form. For example, when the target cell is associated with a chymotrypsin-like activity, the protoxin can be rendered non-toxic by modification with phenylalanine, tyrosine or tryptophan. Since these enzymes, and indeed serine proteases generally, are known to cleave C-terminally, relative to the amino acid target site, when phenylalanine, for example, is linked via an  $[\epsilon-\alpha]$  bond to lysine, the protease will cleave after the alpha carbonyl of phenylalanine, restoring the epsilon amino group of lysine (and the carboxy group of phenylalanine), thereby activating the toxin. Again, when the target cell has trypsin-like activity, the protoxin may be modified with a positively charged amino acid like lysine or arginine.

**[0082]** In cases where the target cell has a protease activity that is the same or similar to conventional proteases, like chymotrypsin and trypsin, there should not be unwanted activation of the protoxin. That is, normally, chymotrypsin and trypsin are localized primarily in the intracellular environment, which is not accessible to the present protoxin medicaments. In the case of disorders where the target cells are associated with elevated levels of outer membrane-associated proteases, which are contacted with the protoxin due to their extracellular location, only the diseased cells will have the capability of activating the protoxin to its toxic form. Accordingly, the present procytotoxins are envisioned as having low levels of toxicity.

**[0083]** The present invention also comprehends a method for the treatment of cancers. According to an embodiment of the present invention, a pharmaceutical composition comprising the inventive protoxin is administered to a cancer patient, whose



cancer cells are target cells possessing, for example, the requisite glutamate carboxypeptidase (or other enzyme for pro-drug conversion) for activating the procytotoxin.

**[0084]** Therapeutic treatment of cancer using the instant cytolytic peptide-based procytotoxin is particularly advantageous because cytolytic peptides are known to be absorbed into the target cell membrane. Even after the target cell is lysed, therefore, the cytolytic peptides are prevented from acting on, and causing undesired destruction of, adjacent non-target cells. For example, see Leippe *et al.* (1991) *Proc. Natl. Acad. Sci.* 88: 7659-7663). Moreover, at least in the case where no extra stabilization steps (described above) are taken, it is noted that the instant medicaments are small peptides, which generally will have a fairly short half-life. Hence, even if small amounts of activated cytolytic peptide escapes the surface of the cancer cell, it should be reasonably short-lived and cause little, if any, destruction of non-target cells.

**[0085]** Particularly preferred embodiments of the present invention entail using  $\gamma$ -glutamate-masked amoebapore or  $\gamma$ -glutamate-masked melittin analogs to treat prostate cancer. It has been recently discovered that prostate cancer cells over-express a type II transmembrane protein, the prostate specific membrane antigen ("PSMA"). PSMA has an intracellular epitope that is immunoreactive toward the 7E11C5 immunoglobulin G monoclonal antibody. Horoszewicz *et al.* (1983), LNCAP model of human prostatic carcinoma, *Cancer Res.* 43: 1809-1818. In prostate cancer patients, PSMA is highly expressed on malignant prostate epithelia, but only marginally on normal prostate glands, and to a lesser degree on benign prostatic hypertrophic epithelia. Pinto *et al.* (1999) Prostate specific membrane antigen, a unique glutamate carboxypeptidase: a review of recent findings, *The Prostate J.* 1: 15-26; Wright *et al.* (1995) Expression of Prostate Specific Membrane Antigen (PSMA) in normal benign and malignant prostate tissues, *Urol. Oncol.* 1: 18-28; Lopes *et al.*, (1990) Immunohistochemical and pharmacokinetic characterization of the site-specific immunoconjugate CYT-356 derived from antiprostata monoclonal antibody 7E11-C5, *Cancer Res.* 50: 623-6428; Troyer *et al.*, Detection and characterization of the prostate-specific membrane antigen (PSMA) in tissue extracts and body fluids, *Int. J. Cancer* 62: 552-558.

**[0086]** The proteolytic domain of PSMA is located on the outside of the cell surface. Upon reaching the target cell, the procytotoxins of the invention, without having to be internalized by the target cell, will have their  $\gamma$ -glutamate residue(s) cleaved and removed, thereby they will be activated. The procytotoxins thus are activated to cytotoxins precisely at the desired site of action, the target cell. The cytotoxin acts directly on the target cell, thereby increasing effectiveness of prostate cancer cell killing. The activated cytolytic peptide immediately inserts into the target cell, leaving it almost no chance of acting upon adjacent, non-target cells. In fact, it is possible that one end of the peptide is already inserted into the membrane before it is activated by PSMA. Furthermore, as discussed above, the activated toxin is neutralized by the membrane therefore after the lysis of the target cell, the cytolytic peptides remain adsorbed in the membrane debris of the target cell and do not leak and harm non-target cells.

**[0087]** The inventors also have recognized that a range of cancer cells, beyond those of prostate specificity, apparently have the ability to cleave the subject  $\gamma$ -glutamate-masked cytolytic peptides (see Examples). On the other hand, normal cells appear to lack this ability, rendering the inventive compounds highly effective in ablating cancer cells, yet leaving normal cells unaffected. Cancer cell types showing sensitivity to the inventive toxins include prostate, ovary, lung and melanoma. A search of public expressed sequence tag databases for PSMA-like molecules indicated that, whereas a number of cancers cells express proteins with significant degrees of homology to PSMA, normal cells do not. This observation likely explains the ability of the inventive molecules to act on a variety of tumor cells, while leaving normal cells unaffected.

**[0088]** In a further embodiment, the procytotoxin is maintained in inactive form by modification with a bulky hydrophobic amino acid, like phenylalanine, tyrosine and tryptophan, or positively charged amino acids, like lysine and arginine. Such protoxins are useful in treating target cells that are associated with a chymotrypsin- or trypsin-like activity. The artisan will be aware of other examples as well. Target cells capable of activating such a toxin include pancreatic cancer cells, which are associated with elevated levels of TMPRSS3, a transmembrane serine protease. Walltrapp *et al.*, Cancer Res. 60: 2602-06 (2000).

**[0089]** The following non-limiting examples are given by way of illustration only and are not to be considered limitations of this invention, and there are many apparent variations within the scope of this invention. The examples illustrate the *in vitro* activity of the compounds of this invention and are illustrative of the studies that the art has relied on for close to half a century as reasonably predictive of the efficacy of cancer chemotherapeutic compounds.

### EXAMPLES

**Example 1: Preparation of  $\gamma$ -glutamate-masked amoebapore analog**

**[0090]** The twenty-five amino acid, C-terminal amidated, amoebapore cytolytic peptide was synthesized by standard solid phase peptide synthesis, except that the  $\epsilon$  amino group of the C-terminal lysine was blocked with a different blocking group from that used to block the  $\epsilon$ -amino groups of the other two lysine residues in the peptide, so that the terminal  $\epsilon$  block could be selectively removed. After selective removal of the blocking group from C-terminal lysine  $\epsilon$  amino group, this amino group was linked to the  $\gamma$  carboxyl group of a first glutamate residue with blocked  $\alpha$  amino and carboxyl groups by solution phase synthesis. This results in the addition of a  $\gamma$  glutamate linked side-chain glutamic acid residue.

**[0091]** The  $\alpha$  amino group of this first glutamic acid residue was de-protected and a second glutamate residue was then linked to the de-protected  $\alpha$  amino group via a  $\gamma$  glutamate linkage between the  $\gamma$  carboxyl group of the second glutamic acid residue and the  $\alpha$  amino group of the first  $\gamma$  glutamate linked side-chain glutamic acid residue. The second  $\gamma$  glutamate linked side-chain glutamic acid residue was also added by solution phase chemistry. If desired, further  $\gamma$  glutamate linked side-chain glutamic acid residues may be added in the same fashion.

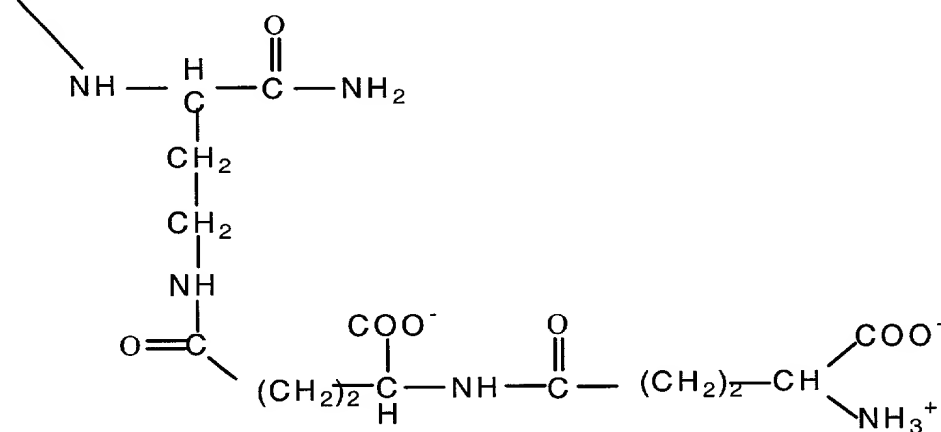
**[0092]** Below is shown a diagram of the initial cytolytic peptide and the procytolytic peptide synthesized by the addition of the two  $\gamma$  glutamate linked side-chain glutamic acid residue to the  $\epsilon$  amino group of the C-terminal lysine.

**Cytolytic Peptide:**

N-Gly-Phe-Ile-Ala-Thr-Leu-Cys-Thr-Lys-Val-Leu-Asp-Phe-Gly-Ile-Asp-Lys-Ile-Gln-Leu-Ile-Glu-Asp-Lys-COOH.

**Procytolytic Peptide:**

N-Gly-Phe-Ile-Ala-Thr-Leu-Cys-Thr-Lys-Val-Leu-Asp-Phe-Gly-Ile-Asp-Lys-Ile-Gln-Leu-Ile-Glu-Asp--



**Example 2:** Assay for the cytolytic activity of the pore-forming toxins

**[0093]** For cell lysis assay,  $10^6$  LNCaP prostate tumor cells were cultured in 48-well plate in 200  $\mu$ l culture medium containing different concentrations of the peptide. The culture medium for LNCaP cell was RPMI 1640 medium with 2 mM L-glutamine adjusted to contain 1.5 g/L sodium bicarbonate, 4.5 g/L glucose, 10 mM HEPES, 1.0 mM sodium pyruvate, 90%; fetal bovine serum 10%. The cells were treated with peptide in a  $\text{CO}_2$  incubator for one hour.

**[0094]** As seen in Figure 1, human prostate cancer cells (LNCaP) are completely lysed after 15 minutes in 50  $\mu$ M amoebapore helix 3- $\gamma$ -Glu- $\gamma$ -Glu, while mouse L-cells remain unaffected after 24 hours under the same conditions.

**[0095]** In order to obtain a more quantitative result, the assay was repeated and decrease in ATP levels was used as a surrogate marker for live versus dead cells. ATP plays a central role in the energy status of the cell and the regulation of enzymatic activity. The intracellular ATP level is strictly regulated. The assay of ATP has been used as a rapid and convenient measure of viable cell numbers. ATP level can be enzymatically determined with firefly luciferase, which specifically catalyzes the hydrolysis of ATP. The

amount of light generated by this enzymatic reaction is directly related to the amount of ATP in the original sample.

**[0096]** For this purpose, the ATP Bioluminescence Assay Kit CLS II from Boehringer-Mannheim (Cat. No. 1699695) was employed. Briefly,  $10^6$  cells in 200  $\mu$ l of medium containing the peptide, as above, were incubated at 37°C in a CO<sub>2</sub> incubator for 60 min. The cells were then lysed with 10  $\mu$ l of 10% Triton X-100. Each lysate was transferred into a tube containing 155  $\mu$ l of distilled water and 25  $\mu$ l of stock luciferase and chemiluminescence was measured in a luminometer as directed by the manufacturer. As can be seen from Figure 3, ATP is dramatically depleted in the presence of either 50 or 100  $\mu$ M peptide, as compared to the controls.

**Example 3:** Specificity for additional tumor types and lack of toxicity

**[0097]** This example demonstrates that the inventive  $\gamma$ -glutamate-masked cytolytic peptides have specificity for cancer cells other than those expressing PSMA. This experiment, utilized a melittin analog having A [ $\epsilon$ - $\gamma$ ]-Glu- $[\alpha$ - $\gamma$ ]-Glu at each of lysines 21 and 23: NH<sub>2</sub>-Gly-Ile-Gly-Ala-Val-Leu-Lys-Val-Leu-Thr-Thr-Gly-Leu-Pro-Ala-Leu-Ile-Ser-Trp-Ile-Lys( $[\epsilon$ - $\gamma$ ]-Glu- $[\alpha$ - $\gamma$ ]-Glu)-Arg-Lys( $[\epsilon$ - $\gamma$ ]-Glu- $[\alpha$ - $\gamma$ ]-Glu)-Arg-Gln-Gln-COOH. Two prostate tumors (PNCap and DU0145), two ovarian tumors (HeLa and SK-OV-3), one lung tumor (LLC1) and one melanoma (B16) were tested. Cultured cells were treated with 1, 10, 50 or 100  $\mu$ M peptide. Results, depicted in Figure 4, show strong lytic activity against all tumors.

**[0098]** The same analog was used to treat a PSMA-expressing prostate cells (LNCaP-FCG), ovarian cancer cells (HeLa) or prostate cells not expressing PSMA (PC3). While 25 and 50 mM concentrations were highly toxic to the PSMA-expressing prostate cells and the ovarian cancer cells, the non-PSMA-expressing prostate cells were relatively unaffected. See Figure 5.

**[0099]** To assess the toxicity of this analog, mice were treated with escalating doses of analog, either subcutaneously or intravenously. At 50, 100, 150 and 200 mM concentrations (50-200-fold higher concentrations needed to kill a mouse using the unmasked melittin peptide) mice remained healthy, apparently unaffected, for weeks

following treatment. These data indicate that the subject peptides should be safe and effective in treating a variety of tumors.

**Example 4:** Treatment of Prostate Tumors with Melittin-Gamma Glutamate *In Vivo*.

**[0100]** Four LNCaP-FCG tumors in nude mice were treated with melittin-gamma-glutamate. Treatment was initiated when the tumor diameter was approximately 2.0 mm in diameter. 33 mg/kg melittin-gamma-glutamate was administered every other day for five weeks. Results, depicted in Figure 6, indicate that tumor volume remained low (less than 500 cu. mm) in all treated mice for the entire treatment time. The tumor volume continuously increased in the untreated control animal to 2000 cu. mm by day 15.

Melittin-Gamma-Glutamate *in-vivo* study -- start date 6/20/01

Day	Volume 1(mm cu)	Volume 2(mm cu)	Volume 3(mm cu)	Volume 4(mm cu)	Untreated Control
1	---	270	---	---	150
3	---	250	---	---	500
5	14	175	---	---	950
8	7.5	269.5	125	---	1200
10	14	231	110	---	1500
12	15.75	486	342	---	1850
15	18	437	150	20.25	2024
18	20	378	175	12.25	---
20	22.5	293.25	170.625	12.25	---
23	40	288	175	9	---
25	60	280	180	9	---
27	60.5	280.5	135	7.5	---
30	28	165	84	7.5	---
32	25	140	84	6	---

**Example 5:** Preparation of procytotoxins inactivated by an inhibitor

**[0101]** This example demonstrates that lytic peptides can be inactivated by the attachment of an inactivator that sterically hinders lytic peptide insertion and pore conformation, rendering the peptide non-toxic.

**[0102]** As an example, melittin may be inactivated by attaching a phage filament, other peptide, or a biotin-streptavidin microbead, according to the following:

Gly-Ile-Gly-Ala-Val-Leu-Lys-Val-Leu-Thr-Thr-Gly-Leu-Pro-Ala-Leu-Ile-Ser-Trp-Ile-Lys-Arg-Lys-Arg-Gln-[Gln-Gly-Ala-Ile\*Gly-Gln-Pro]-(X), wherein \* denotes an MMP

cleavage site and (X) is an inactivator. MMP cleavage will yield a melittin peptide with three additional amino acids on the C-terminus (Gly-Ala-Ile), which should not interfere with pore formation.

**[0103]** Other cleavage sites can also be used. If a prostate specific model is desired, a prostate specific antigen (PSA) cleavage site can be employed by replacing the MMP site for Ser-Ser-Phe(or Tyr)-Tyr, or any of the other PSA cleavage sites. PSA is an endopeptidase and sequences for PSA cleavage have already been identified (Coombs *et al*, *Chem Biol*, 5(9): 475-88, 1988).

**[0104]** The procytotoxin may further comprise a targeting sequence, such as Biotin-Gly-Gly-Cys-Asp-Cys-Arg-Gly-Asp-Cys-Phe-Cys (RGD-4C)  $\alpha_v\beta_3$  integrin targeting peptide or biotin-anti-fibronectin ED-B antibody.